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Refinement of a Civil and Natural Resources Engineering Capstone Design Course

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ABSTRACT

CONTEXT

The University of Canterbury offers a Capstone Engineering course for final-year civil and natural resources engineering undergraduate students. The course runs parallel to the research course before graduation. The primary goal of the course is to challenge students with a complex engineering problem for which they must utilise not only their technical skills but also other skills such as functioning well within a team, time management and communicating findings. Employers expect that their employees are ready for the challenges of the real-world environment. Therefore, preparing students as job-ready graduates in an uncertain future (Scott, 2019) becomes a primary focus. With the support of a mentor structure, the student-mentor relationship between students, academics and industry professionals is enhanced. The course design is based on the individual component of Problem Based Learning (PBL) (Yew & Goh, 2016) and the group component of the PBL. It provides students with a place of investigation within the research-based innovative and creative framework (Sinay, 2018). It is also primarily based on Kolb's experiential learning theory (Kolb, 1993) while linking to Design Thinking (Brown, 2008) and Tuckman’s Development Sequence in Small Groups (Tuckman, 1965).

PURPOSE

The capstone course was developed based on a year three course (out of four years). The previous course focused on the initial concept design phase only. The newly expanded and now a year four course has an extension on the concept phase to the developed design phase. Previously, the mentors would provide overall guidance on all disciplines in a small classroom with several teams of student engineers. Now, students select a discipline at the start of the course and receive specialised instruction in tutorials and workshops. The students are given structured and guided information while retaining some open ended-ness within the design challenge. This approach fosters learners' increased level of independence (O'Steen & Spronken-Smith, 2012).

APPROACH

The motivation for the re-design and further development of the previous course structure was based on anecdotal evidence from student evaluation and the work experience report write-up. It was evident that before this course's development, graduates needed much guidance at their first consultancy work placement (R. Chen, personal communication, 8th July 2022). It was also evident that the students struggled to learn from various levels of mentor guidance in the previous course, so they had to resort to informal Peer Assisted Learning (PAL) (Maheady, 1998) for support (R. Chen, personal communication, 8th July 2022). With the new course, it is evident that the students acquire design process skills, technical competency through the application, and professional capabilities and project management skills (Anonymous, 2022). It must be noted that the design solutions are developed and evaluated considering all relevant contexts beyond the technical requirements. These include public health and safety, whole-life cost, net-zero carbon, cultural, societal, and environmental considerations.

ACTUAL AND ANTICIPATED OUTCOMES

The actual outcome of the course is to equip the students with firsthand experience in performing and developing technical and non-technical skills in a simulated professional work environment. While students work in teams, each student has distinctive responsibilities and a clear outline of collaborative elements in the technical sense. It is entirely blended learning (Graham, 2006), supported by workshops, discipline-specific tutorials, and lectures. Mentoring through academics and industry professionals is provided to help the open-ended design process. This course also develops professional capabilities, including Continuing Professional Development and Teamwork Reflection, supported by the structured workshops. It was anticipated and is already evident that the students will now have learnt the design thinking process, obtained technical competency, gained professional capabilities and became more independent job-ready plus graduates.

CONCLUSIONS

Providing students with real-world experience in an educational setting is likely valuable when the graduates land their first job. This is supported by the evidence from students' feedback working in a consulting environment such as engineering design and project management roles where they had to apply the technical competencies and professional capabilities learnt at the university. The course provides a 'safe space' for students to take design risks, ask questions and practise professional engineering. Students are then well equipped with the skills required to thrive in a professional context after graduation. The course structure will be further refined based on focus group interviews, feedback received in course evaluations and surveys with recent graduates after applying the skills gained in their first work placement.

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KEYWORDS

Capstone Engineering; Experiential, Problem Based, Blended Learning; Job-Ready Plus Graduates for an Uncertain Future

1. Introduction

1.1 Context

Course evaluations are usually heavily relied on for assessing the effectiveness of tertiary education for chalk-and-talk courses. Depending on their first job placement, students may not immediately see the benefits of such an exercise for a final-year capstone course. Furthermore, the structure of a capstone course will differ from other courses, and students are less familiar with the capstone design course structure. An evaluation of practical work reports of civil and natural resources engineering students is well suited to provide insights regarding the benefits students have gained by completing a capstone course in their final year of study. By completing the practical work report, the early career engineers reflect on their practical work experience and how it relates to the courses they have taken as part of their degree curriculum. Regular end-of-course capstone course evaluations cannot provide information regarding their relevance to achieve key learning objectives and graduate attributes due to the timing late in the degree programme and before students start their first work placements. Therefore, assessment of the effectiveness of a capstone course needs to be supplemented by quantifiable post-graduation evaluations, which in turn can then be used to improve such courses further.

1.2 Course expectations

A vast amount of literature on project-based learning and problem-based learning is available to inform the structuring of an engineering capstone design course, for example by Mills and Treagust (2003). Problem-based learning aligns well with requirements in the engineering profession, as unexpected problems often challenge engineers. Such challenges might occur on-site or in the design office, which requires further research. Observing and identifying problems during the initial stages of design or as the construction progresses is vital to fluid progression and successful project completion. Therefore, training students to identify issues using observation skills and then utilising their creativity, research and technical skills to resolve them is crucial.

1.3 The current course

The course is divided into Concept and Developed Design Phases. Lectures at the beginning of a given week are structured in a way that is closely linked to the workshops and tutorials of the week, while considering project progression (Canterbury, 2022). Discipline selection, including structural, geotechnical, stormwater, water supply, wastewater and transportation & roading engineering, is based on students ranking their preferred discipline, grade point average, and the courses they have taken previously. Design teams are then formed such that a team is comprised of students that cover the entire range of disciplines of the design project.

Peer and self-evaluation assess students' contribution to team deliverables. Students have to demonstrate their effectiveness to function well within a team. This is supported by the teamwork reflection workshop where they must consider working with others in a multi-disciplinary team setting where they are provided with good examples of civil engineers working in a team and a matrix where they could identify what they need from each other. A report write-up on their teamwork reflecting on the effectiveness is part of the requirements at the end of the course.

Creativity is an essential element in this course. Students come up with their solutions individually and work as a team to discuss, evaluate and select the contributions of all team members. They need to ascertain that not only the design of sub-systems meets the requirements, but that the entire design achieves the design goals. An example is the selection of an optimum location for wastewater treatment systems utilising gravity to help the flow, thereby being well aligned with other design elements. Another example is how a column in a building is used for lateral loading

for a superstructure and the substructure for soil pressures, thereby linking to the geotechnical design aspects of a foundation design. Upon completion of the concept design phase, each team must have identified a design solution that meets various criteria. The critical criteria are that the design solution satisfies the client's requirements, aligns with cultural values & principles, minimises environmental impact, is sustainable, increases resilience, is cost-effective, and reduces risk. The engineering decision-making workshop equips the students with the skills to identify the most suitable solution. Cultural values & principles need to be woven into the design from the beginning and this is reinforced by lectures and a workshop to practice their ability to be bi-culturally competent and confident in a project. Further workshops cover site scoping, sustainability, costing, safety in design, risk assessment, consenting, and project management.

In the second project phase, the teams develop the concept solution to developed design standards. A report writing workshop further enhances their writing skills to allow students to write coherently and concisely to communicate their recommended solutions.

It was particularly challenging to run a site visit during the Covid-19 pandemic, so a virtual site visit was developed consisting of a client site overview and discipline-specific talks with drone & 360 videos to allow students to identify any local issues, site constraints and client wishes. Students also physically visit a site with the discipline-related project work to produce sketches, take notes, and observe and understand the design process from on-site explanations by industry professionals and academics. This is complemented by the site scoping tutorial and engineering decision-making workshop in teaching week one. At the same time, students start to think about their continuing professional development options to become independent lifelong learners by identifying information requirements and selecting appropriate information from open literature and other sources to complete the project. Students are asked to submit an interim report to receive instructor comments and a final submission at the end of the course to complete their in-course continuous professional development training.

A multi-choice, matching, and essay-type project management and economic decision-making quiz allows for an assessment of the engineering management principles and economic decision-analysis experience per team member.

2. Literature review

2.1 Evaluation frameworks and methods

A method such as aligning capstone course learning objectives with attributes of outstanding engineers can be a way to improve a capstone course. A matrix with weighting for each attribute was used to calculate the total scores taking into account the corresponding learning objectives. This will help students succeed after graduation and quickly progress in their engineering careers. In addition, a broader survey audience will help further enhance this method. There are several universal attributes and performance factors for a highly skilled engineer (Davis et al., 2003):

- Highly universal: Motivation, judgement & decision making, professional/ethical, teamwork, and communication
- Moderately universal: Innovation, client/quality focus, business orientation, and change management
- At graduation: (1) accepting responsibility, (2) exhibiting integrity and ethical behaviour, (3) being an effective team player who respects others, and (4) remaining open and flexible to change

Another way to evaluate the course was to use three framework components, including observation, model and interpretation, incorporating different perspectives of the educational researcher, students and practitioner. It is a comprehensive framework that can be used to evaluate the course (Beyerlein et al., 2006). Systematic Inventive Thinking (SIT) tool (Kim, 2019) was used as a simplified Theory of Inventive Problem Solving (TRIZ) to evaluate creativity. This

can be adopted to assess students' creativity. An evaluation at the beginning of the course compared to the review after the course can be used to understand whether the course met students' expectations. This framework can also be adapted to other factors, such as learning objectives (Kim, 2022).

2.2 Survey questions

Rather few studies have been carried out to date on students' perceptions of the capstone design project and the uncertainty that students might face when starting their first job placement (Ola Rashwan, 2020). Such research is beneficial considering students' emotional health when landing their first job, as the capstone course may have boosted their confidence and allowed them to conduct their work more independently and efficiently from the beginning of their career. A detailed self-learning rubric can help students reduce uncertainty due to inexperience with working on complex engineering design throughout the capstone engineering course. This has been adopted in the integrated capstone design course. An example of an informative open-ended focus group question to the graduates is: How much more confident have you become in undertaking engineering design after having gone through the capstone project experience?

The course type, whether elective or mandatory, can influence the pass rate of the course (Kim, 2022). Kim (2022) reported that the capstone course pass rate turned from 70% to 100% by changing the course from mandatory to elective. Therefore, it was conclusive that the motivation for an elective was high. A Likert-scale question can be: Would you have preferred the course to be an elective?

Obtaining opinions on a particular aspect of the course can help improve the course (Kim, 2019). The factors can include: the fairness of peer and self-evaluation; milestones achieving objectives; progression towards a particular goal; classroom experience; development process for a specific objective; and a suggestive question on a beneficial exercise. For example, an open-ended question on whether a particular type of work in the industry could be helpful to learn before graduating, and the answer could be implemented as an exercise in the course.

A capstone course's difficult-to-assess attributes can be used to form questions (Brennan & Li, 2017). Questions posed to the participants can relate to how well these attributes have been taught in the course. Examples of such attributes are:

- Course learning outcomes
- Graduate attributes
- Classroom assessment about learning outcomes and graduate attributes
- Lifelong learning
- Self-efficacy

2.3 Survey results evaluation methods

Statistical tests such as t-tests and Kruskal-Wallis H test, including computation of mean, mean difference and significance, can be used to analyse the survey results (Guo et al., 2022). The results can be compared before and after the design course to explore the improvement, e.g. whether it is statistically significant, and look at how significant the average difference is (Kim, 2020). Another method, Cronbach's alpha coefficient and Pearson's correlation coefficient were used to evaluate the findings (Kim, 2019).

2.4 Research question

An education action research cycle starts from observation, reflection, and planning followed by implementation. This research paper aims to address the first two stages of the process. Will educational research help improve the capstone course, graduate work readiness, and employer satisfaction? It should manage this over several research cycles when the results inform the course improvement plan and implementation.

3. Preliminary results

The University of Canterbury Faculty of Engineering practical work reports consists of work report and self-review assessment write-ups that are compulsory requirements to complete the BE(Hons) degree. Students are asked to complete the engineering work experience course consisting of 800 hours of work experience, usually split into half practical and half professional. Students can choose when to complete these work experiences; they typically start their first experience in a practical work placement, such as construction labour, followed by a professional work experience, such as consultancy and project management. In their self-review discussion section of the work report, they were asked to reflect on their work experience and how it relates to the courses taught. This informs academics on whether a particular course may be related to their practice and can also be used as a focus group interview question. It was then discovered after the course was run for the second time, students started to comment on the usefulness of this capstone course in their work report write-up, and this only appears in their professional work experiences. Insightful feedback samples are provided in the Appendix. All the insights have been carefully thought through to form questions as potential survey and focus group interview questions for the graduates (G) and employers (E) listed in Table 1.

Table 1: Questions for employers and graduates

Questions	For whom	Question type
Did the course provide sufficient foundational knowledge and experience for you to conduct your first formal engineering work with little guidance from the seniors? If so, how?	G	Open-ended and Likert-scale (mixed)
Did the course improve your communication skills while facing external parties such as the client or contractors? What about internal parties such as colleagues face-to-face or remotely? If so, how?	G, E	mixed
Did the teamwork experience gained in the course improve your understanding of peer-reviewing engineering work conducted by another engineer? If so, how?	G	mixed
Do you think the peer review process will be helpful as a skill learned at the university?	G, E	Likert-scale
Were the project management aspects of the course useful for consultancy work, such as invoicing, timesheets and general communication with team members and clients?	G, E	Likert-scale
Would Computer-Aided Design (CAD) be practical if included in the course?	G, E	Likert-scale
Are the design process calculations you conducted in the course similar to real-world engineering? If so, how?	G	mixed
The course provided guidance in almost all aspects of engineering design. When you are in the industry, you are on your own when researching for any information related to engineering design. Did the course help you become more independent? If so, how?	G	mixed

4. Proposed options to improve the course

4.1 Limitations

Understanding the approach's limitations will be required before conducting this study as proposed in the following sections. A non-exhaustive list of consideration includes: a mixed-method approach; survey fatigue; unrealistic change of course delivery by before and after surveying, so the timing of surveying may be important; and the number of responses required to achieve the required significance level for statistical analysis. Therefore, a data collection plan will be useful.

4.2 Survey

Survey questions measured by Likert-scale can be asked to obtain a score for statistical analysis (Joshi et al., 2015). Surveys for employers and graduates will be conducted through Qualtrics. For current students, surveys can be done before the course through Qualtrics and after the course through add-on questions to course evaluations.

4.3 Focus group interviews

Open-ended questions can be asked in a focus group interview for group discussion (Vaughn et al., 1996). The formation of employee focus groups can be based on the number of years since graduation and the job type. This can be further categorised into sub-job types, e.g., structural and civil engineering consultancy and construction project management. The formation of employer focus groups can be based on the company's business type and size. For ethical considerations, care must be taken to guide the focus groups not to release confidential information in their discussion.

4.4 Analysis

Coding and mapping the qualitative data will be accomplished using NVivo to sort any themes, attributes and sentiments, and a decision on the specific coding method is needed. Zoom-recorded meetings can be used for transcripts. Quantitative data from the survey for graduates and employers can be used to validate the qualitative data. To do so, we must ensure the survey questions complement the open-ended questions. Data will be gathered via surveys at regular intervals. To avoid survey fatigue of employers and employees, these will be contacted every other year, while graduates' data will be obtained annually, as they will submit their work reports. The factors can then be plotted against learning objectives while considering institutional goals and Washington Accord to form a matrix to compute the Learning Objective Score, as shown in Equation (1) and Table 2.

$$\text{Learning Objective Score}_{\text{(Graduate or Employer)}} = \sum_{x=0}^{n} W_x(A + B + C) * LO \quad (1)$$

Table 2: Example analysis table based on Davis et al. (2003)

Research Year 1	**Weighting (W_x = 1~5)**	**Presence of Goals (A, B and C=1 or 0)**			**Presence of Learning Objectives (LO=1 or 0)**			
Factors (x) highest to lowest weighted	**Graduate or Employer**	**A**	**B**	**C**	**Lifelong learning**	**…**	**…**	**…**
Research and application	4	1	1	1	1	0	0	
Identify gaps in knowledge	3	0	0	1	1			
A= University of Canterbury Graduate Attribute					4			
B= University of Canterbury Work Readiness Skills					4	Etc		
C= Washington accord					7	.		
1 = present in the aspirational goal or objective; 0 means absent					Sum=15			

The factors of high weighting but absent in the learning objectives should be considered immediate future improvement goals, but it may not be practical to inform the university or Washington Accord to alter their expectations. At this stage, the plan is to conduct this research continuously, thereby improving the course and reporting intermediate results as deemed applicable. Further research can be completed on whether these essential factors were taught well in the class and compare this data between research years to see whether there is an improvement. The results are considered different at different locales, so it is important to find local groups of employers and international companies considering their size, business type etc., to understand the data further. Although having a diverse range of data will help without the related employer, it will be ideal to have a group of employees who these affiliated companies currently employ to have a complete picture of the data.

4.5 Further considerations

Anonymous comments can be obtained from faculty, industry professionals involved in the course, clients and students enrolled in the course at each milestone review stage, including: preliminary design review; concept design review; and final design review (Qattawi et al., 2021). Additional attributes can be introduced to help improve the course, including: self-regulation and devotion; nourishing respective competitiveness; attaining capabilities to deal with incomplete or inaccurate information; team-building exercises conducted pre-course. Students are often anxious about whether they will succeed in this course, so an early introduction to this course may help. The online capstone process is inferior to offline, so turning the course into purely online engagement should be avoided (Kim, 2022). Personal rapport can be improved in an engineering capstone design course. Grand price and encouragement awards can be given to students to incentivise them to work hard (Kim, 2020), but this should be adopted in a meaningful way. Practical work reports can be used to inform the course in the absence of a bi-yearly analysis. Further comparison to other studies will be required to understand the expected results. Relevant topics such as right to repair, COP26, UN sustainable development goals could be further incorporated in the course. Course structure can also be altered to better suit the institutional constraints.

5. Conclusion

The current literature review provides a theoretical framework for methodology and methods that could be used in this research. This research will inform the next steps of the course. And further evidence will be incorporated into the presentation of this paper in the conference.

Appendix

Professional Capabilities and Project Management

> *The project management aspects were particularly useful… This includes invoicing, timesheets and general communication with team members and clients. Looking back at the work experience with this civil construction project, … to do with project management work… Understanding the processes of how a project timeline/schedule … can have delays … Understanding critical path … suddenly change activities. The learning from the course 413 was something that I had found very useful as it was a start to finish project that gave me an idea of the design process that is used in the industry. … This combined with the other soft skills I had developed in … in terms of being posed a question and then having the ability to find supporting documents to prove the theory that … Since detailed drawings were not required … client wanted to see preliminary sizing … visualising initial drawings was taught in 413.*

Technical Competencies and Design Thinking Process

> *One of the larger projects I am working…The calculation work I completed for this project was also very similar to my 413 paper in university, therefore was easiest for me to get the hang of. The work I did with CAD in 413 will help me in the future when I must use CAD in projects such as Integrated Transport Assessments which are commonly done at this company. I also applied skills from 413…when determining the flows of the channels in…specifically applying Manning's equation for open channel*

flow, and orifice flow calculations (413). I used my experience of ensuring exact requirements had been meet which I gained during 413. The design aspects including drawings and interpreting drawings related to aspects learnt in my final year course Integrated Civil Engineering Design 413 as did the sizing of sediment ponds… another aspect that my courses taught me was my thinking process more than the engineering knowledge. The course introduced me to a range of different design standards used within engineering design.

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